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THE EFFECT OF POST-HARVEST TREATMENT ON THE QUALITY OF SWEET CHERRIES DURING STORAGE

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ABSTRACT
Cherries are a traditional commodity grown in the Czech Republic. Placing into a cold room is essential for the fruit to be preserved in the long term. Even if optimum storage conditions are followed, the shelf life is relatively short. This study observed the effect of packing cherries into the Xtend polymer wrap on slowing down the degradation of the fruit during the storage period. The experiment was conducted using 4 varieties of the sweet cherry (*Prunus avium* L.) from the identical site (Stošíkovice, Czech Republic) - 'Vanda', 'Kordia', 'Sweetheart' and 'Regina'. Part of the fruit was stored at 20 °C for 7 days (conditions in retail chains) and other part of the fruit was stored at 1 °C for 50 days, first half of fruit was stored in Xtend polymer wrap and second half in the normal air conditions. Changes were also investigated in fruit quality parameters (soluble solids, titratable acidity, weight loss, peel firmness and respiration intensity) under the shelf life conditions when the fruit was placed at the distribution temperature of 20 °C after removal from the store and analysed after 5 and 10 days. Packed fruit exhibited significantly lower weight loss than unpacked fruit. Unpacked fruits showed visible signs of wilting and it is connected to the water loss and loss of turgidity of fruit. Soluble solids content and titratable acidity reduced generally less in unpacked fruit, which was probably related to the higher weight loss in this variant. Between the packaged and control fruit firmness was not statistically significant. Carbon dioxide production characteristic the intensity of respiration was typically higher at 1 °C for fruit packed in the Xtend film. This fruit, however, largely responded by reducing the intensity of respiration when removed from the store and placed at 20 °C, whereas in unpacked fruit there was a several-fold increase in carbon dioxide production under such conditions.

Keywords: *Prunus avium* L.; sweet cherries; Xtend; carbon dioxide; weight loss

INTRODUCTION
In the territory of the Czech Republic, growing sweet cherries (*Prunus avium* L.) has had a long tradition from a historical perspective. The first mention dates from the 14th century. According to 2015 statistics, the production of cherries in the country was more than 9,900 tonnes throughout the total area of 1,429 hectares. Health benefits of cherry fruit are relatively high, mainly due to the content of phenolic compounds, such as procyanidins, anthocyanins and phenolic acids **(Liu et al., 2011; Usenik et al., 2010)**. With the high antioxidant capacity, consumption of cherries has been shown to reduce the risk of cancer **(Kang et al., 2003**) and other diseases **(Jacob et al., 2003)**. The storing potential of cherries is limited and the shelf life is relatively short. Fruit is sensitive to deformation during post-harvest operations and features relatively quick reduction of the flesh firmness **(Ceponis et al., 1987)**. Low temperature is the basic parameter for storing; it keeps the fruit firm longer and reduces the degradation of the colour **(Shick, Toivonen, 2002)**. Reported as recommended conditions to store cherries is the temperature range 0 to 2 °C and the relative humidity of 90% to 95% **(Crisosto et al., 1993; Looney et al., 1996)**. Despite the compliance with the above conditions, the shelf life is shorter compared with other kinds of fruit. The aim of this study was to determine the effect of packing the fruit in the Xtend film on extending the shelf life of cherry fruit while maintaining commercial quality. Films produced using the Xtend technology pass any excess moisture through the walls while keeping the RH value at 90% to 95%. Slowing down the process of biological synthesis and ethylene production in stored fruit, the film can be assumed to have effect on the time of preservation if used.

MATERIAL AND METHODOLOGY
Varieties and storage conditions
The experimental part monitored a total of 4 varieties of the sweet cherry (*Prunus avium* L.) - 'Vanda', 'Kordia', 'Sweetheart' and 'Regina'. The fruit originated from the identical site (Stošíkovice, Czech Republic) and were harvested at the optimum harvest date ('Vanda' - 24 June, 'Kordia' - 30 June, 'Regina' & 'Sweetheart' - 10 July). They were sourced from managed orchards, were undamaged and of adequate quality, with a size tolerance specified for one fruit with a pedicle ('Vanda' 8.9 ±0.3 g, 'Kordia' 10.9 ±0.2 g, 'Regina' 10.75 ±0.25 g, and 'Sweetheart' 9.9 ±0.4) The stalk of each fruit corresponded to the variety.

One third of the fruit was stored at 20 °C for 7 days to simulate conditions of distribution of fruits in retail chains ("shelf life"). The second third of the fruit was stored under refrigerated conditions, i.e. at 1 °C, for 50 days. The surveyed fruit parameters were evaluated after 30 and 50 days. On each sampling, simultaneously, a portion of the fruit was removed from the refrigeration room and placed into 20 °C (shelf life), where the fruit was analysed after 5 and 10 days. The last third of the fruit was stored under the same conditions as the previous part; the fruit, however, was put into a polymer wrap (Xtend) and sealed hermetically.

Weight loss

Each sample for determining the weight loss was made up of 20 pieces of fruit in triplicate. Fruit was weighed on each sampling date as well as under the shelf life conditions. As part of the results the loss was expressed as the percent loss from the initial weight.

Titratable acidity

Total titratable acidity (TTA) was estimated by alkalimeter and expressed in $g.kg^{-1}$ malic acid equivalent of fresh matter, the soluble solids content (SSC) was expressed by the index of refraction (°Bx).

Peel firmness

The determination of peel firmness was done using the TEXAN 2000 device. The fruit was loaded using a punch, a diameter of 5 mm and the loading rate being 8 $mm.min^{-1}$. The evaluation unit for the variety and storage time represented thirty pieces of fruit that were penetrated just from one side of the fruit. The resulting value was expressed in N.

Respiration intensity

The fruit respiration intensity was assessed based on the monitoring of CO_2 production. 200 g of cherries were put into an air-tight container of 1,000 mL; 1 mL sample was taken using a chromatographic syringe (Hamilton Syringe 140 mL HD TCA Analytics AG, Switzerland) once the time of exposure (1 hour) passed. The sprayed volume was determined using a gas chromatography unit (4890D; Agilent Technologies Inc., Wilmington, USA). The measurement of CO_2 production was carried out using the HP Al/KCl column that was connected to a thermal conductivity detector (TCD). Helium was the carrier gas, the flow rate being 1.0 $mL.min^{-1}$. The results were expressed in mg of CO_2 $.kg^{-1}.h^{-1}$.

Statistical analysis

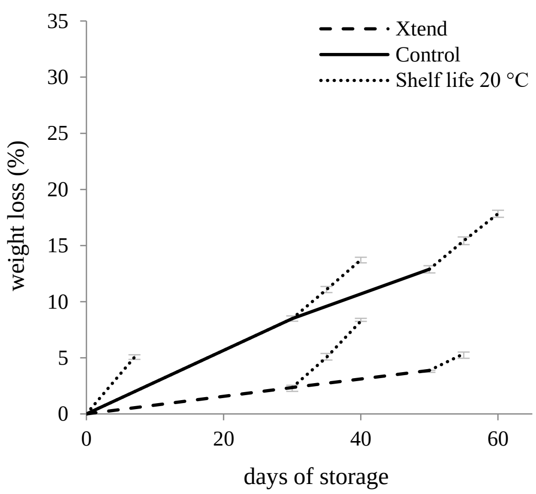
Analysis of variance was conducted and the results were compared using Tukey's multiple range test (p <0.05). Statistical analysis was carried out using the Statistica 12 programme (StatSoft, USA). The obtained results were averaged and standard deviations were calculated.

RESULTS AND DISCUSSION

The loss of weight due to evaporation are clearly distinguished by the variety and ripeness on the tree from which it follows that the early variety 'Vanda' has lost weight up to 9.5% after 7 days of storage at 20 °C; it was demonstrably the largest number compared with other surveyed varieties (Figure 1 – 4). 'Sweetheart' had a weight loss of only 5%, which was significantly the lowest value compared with other varieties. The stalk presence is the essential criterion for minimising losses due to evaporation during the storage of cherry fruit **(Smith and Whiting, 2011)**. For fruit stored under refrigeration conditions differences were observed among different varieties. For 'Vanda', the loss of weight after 30 days was 11.9% when stored in bulk while only 3.2% when wrapped in the Xtend film. Reduction of evaporation was almost ¼ compared with the bulk cherries. The wrapping material had, therefore, a demonstrable effect on lost weight. After removal from the store the loss of weight was identical in both variants under twenty degrees without the use of packaging materials. A further decline was recorded after 50 days of storage, reaching 18.6% of the original weight in case of bulk cherries and 6% when using Xtend. The highest loss of weight after 50 days storage was showed in the fruit of the 'Regina' variety (Figure 2). The weight of unpacked fruit decreased by 23.1% for this variety; when using Xtend, it was only 5.2%. As with the 7-day storage at 20 °C, 'Sweetheart' was the variety to show the least loss of weight after 50 days at 1 °C (12.9% for unpacked fruit, 3.9% for the Xtend wrap).

Soluble solids content in observed varieties ranged from 15.4 for 'Vanda' (Figure 8) to 22.2 °Brix for 'Regina' (Figure 6). 'Kordia' and 'Sweetheart' have an average sugar content of 19.4 °Brix (Figure 7) and 21.88 °Brix (Figure 5), respectively; similar values for these varieties were monitored by authors of other reports **(Harb et al., 2006; Turner et al., 2008)**. During the seven-day storage at 20 °C, the difference between the original and the resulting soluble solids was statistically insignificant; only 'Kordia' had a significantly higher sugar content (0.8 °Brix). For other varieties, there was only a slight increase in sugar content.

For all the varieties, a demonstrable increase in soluble solids was showed only for unpacked fruit after 50 days of storage under refrigerated conditions (1 °C). This was probably due to evaporation of water and concentration of solids. Conversely, for fruit packed using Xtend, where the weight loss was significantly lower, reducing the content of soluble solids was confirmed.



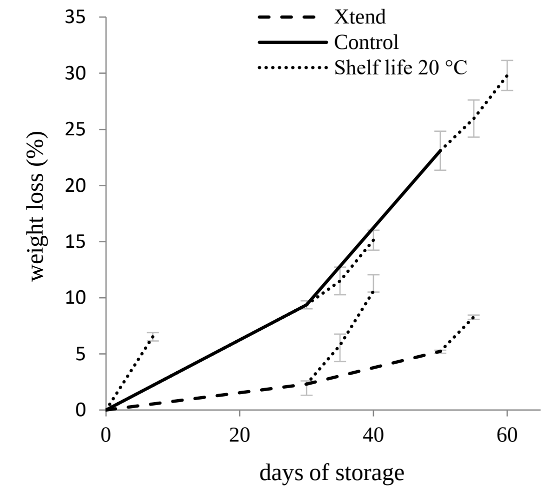


Figure 2 Loss weight for the fruit of the 'Regina' variety when stored at 1 °C, shelf life conditions.

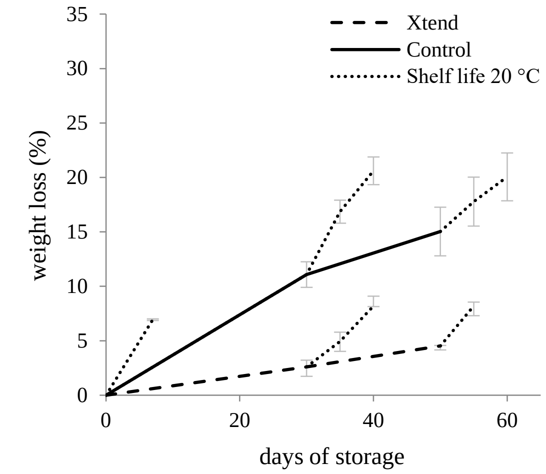


Figure 3 Loss weight for the fruit of the 'Kordia' variety when stored at 1 °C, shelf life conditions.

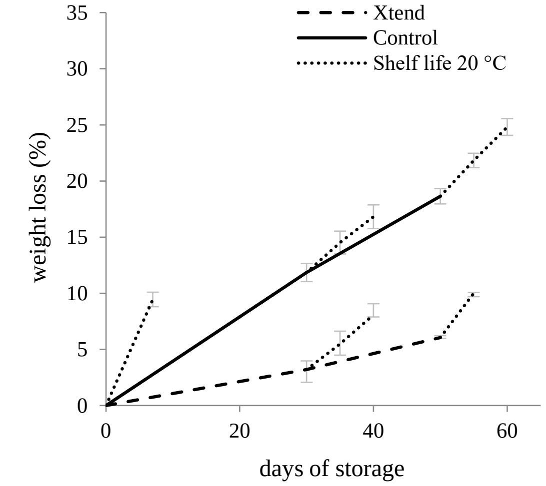


Figure 4 Loss weight for the fruit of the 'Vanda' variety when stored at 1 °C, shelf life conditions.

The reason was probably a negative balance of the rate of ventilating sugars to the cases of the lower loss of weight, which is also confirmed by the results of other studies **(Petersen and Poll, 1999; Ben, 1991)**.

Titratable acidity of the fruit at harvest maturity ranged from a maximum value of 8.1 g.kg^{-1} ('Kordia') up to 5.6 g.kg^{-1} ('Vanda'). During the seven-day storage at 20 °C there was an evidence of decline in titratable acidity observed in the 'Regina' and 'Kordia' varieties (Figure 10 and 11). For 'Sweetheart' and 'Vanda', the latter possessing the lowest acidity, no significant changes were found (Figure 9 and 12). From the results it can be assumed that part of acids are ventilating, causing their decline. In this regard, 'Vanda' and 'Sweetheart' are the varieties that have demonstrably a lesser tendency of ventilating acids compared with 'Regina' and 'Kordia'.

In all the fruit that was stored at 1 °C there was a reduction of titratable acidity after 50 days of storage while the rate of degradation of acids was faster for the fruit packed in Xtend. 'Kordia' was the variety observed to show the greatest loss, when packed fruit contained 2.9 g.l^{-1} and unpacked fruit 1.3 g.l^{-1} less acidity. Fruit that contained lower amounts of titratable

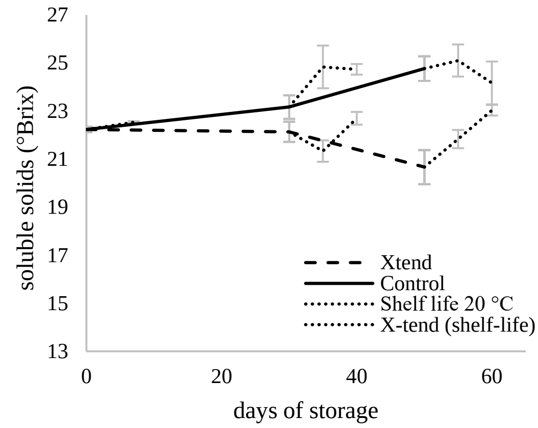


Figure 5 The levels of soluble solids for the fruit of the 'Sweetheart' variety when stored at 1 °C, shelf life conditions.

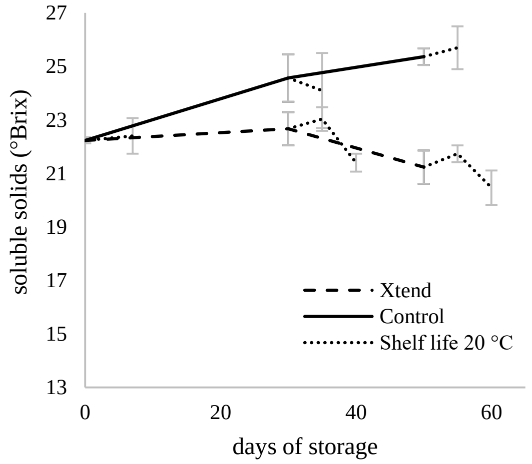


Figure 6 The levels of soluble solids for the fruit of the 'Regina' variety when stored at 1 °C, shelf life conditions.

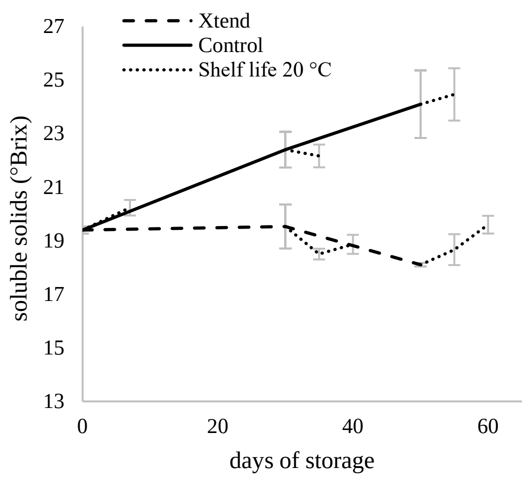


Figure 7 The levels of soluble solids for the fruit of the 'Kordia' variety when stored at 1 °C, shelf life conditions.

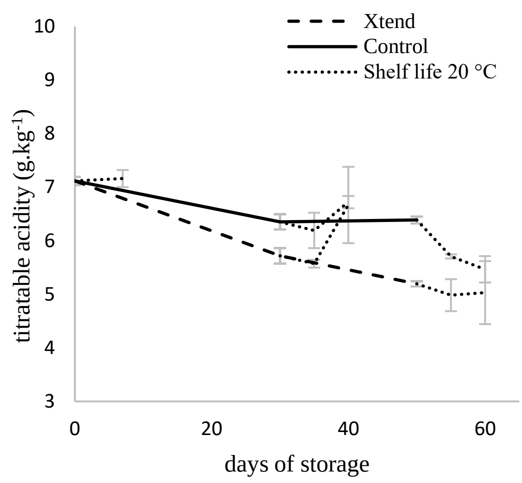


Figure 9 Titratable acidity for the fruit of the 'Sweetheart' variety when stored at 1 °C, shelf life conditions.

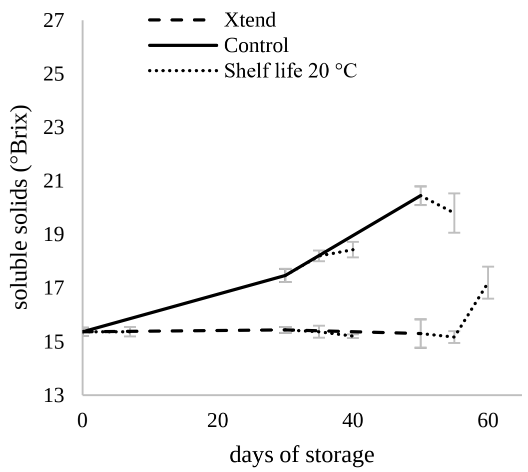


Figure 8 The levels of soluble solids for the fruit of the 'Vanda' variety when stored at 1 °C, shelf life conditions.

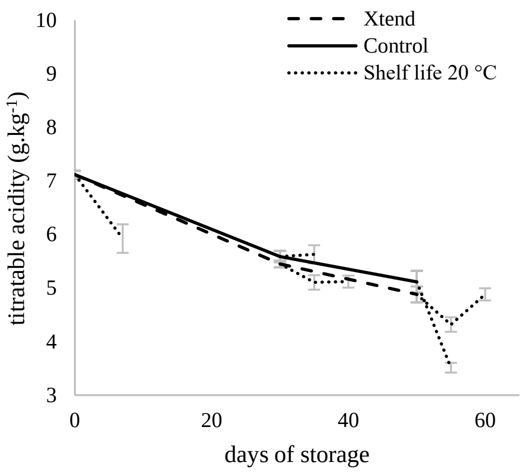


Figure 10 Titratable acidity for the fruit of the 'Regina' variety when stored at 1 °C, shelf life conditions.

acids at harvest time showed a lower rate of degradation during storage. The 'Vanda' fruit contained 5.6 $g.l^{-1}$ titratable acids at the beginning of storage. After 50 days of storage this value decreased by 0.5 $g.l^{-1}$ for unpacked fruit and by 1.5 $g.l^{-1}$ when using the film.

Differences between the fruit firmness at harvest and at 20 °C after 7 days were not statistically significant. 'Sweetheart' exhibited the lowest fruit firmness (Figure 13); the highest firmness after harvest and after seven-day storage at the distribution temperature was seen in the 'Regina' variety (Figure 14). Average values ranged from 20.4 N ('Sweetheart') to the firmest fruit (25.1 N) of 'Kordia' (Figure 15). The standard deviation at unequal diameter ranged from 2.4 to 5.4 N. At harvest, firmness ranged from 20.4 to 25.1 N. After 7 days of storage, 'Regina' was the firmest variety (24.3 N), other varieties ranging from 21.2 to 23.6 N.

Packed and unpacked samples did not significantly differ in terms of fruit firmness when stored at 1 °C. During a prolonged storage period (50 days + shelf-life) fruit unpacked in the film showed more significant weight loss; evaporation of water was causing wilting of the fruit, which also corresponded to some extent of higher firmness. When wrapped in a film, fruit should keep its firmness and green colour of the stalk **(Padilla-Zakour et al., 2004)**. After removal of the fruit from the store into the shelf life mode, however, any significant effect of using Xtend on changed firmness was not observed.

A semipermeable film, Xtend exhibits a constant permeability to physiological gases. During harvest ripeness, which coincides with the value of respiration intensity, the varieties in Figure 17 are shown by maturation on the tree; i.e., the 'Vanda' variety ripens about 7 days sooner than 'Kordia' and about 16 days sooner than 'Sweetheart' and 'Regina'. In addition, 'Regina' and 'Sweetheart' exhibit a maturity difference of four days in favour of 'Regina'. The degree of ripening on the tree by the criterion of respiration intensity is not demonstrable. During subsequent storage at 20 °C, there was reduced

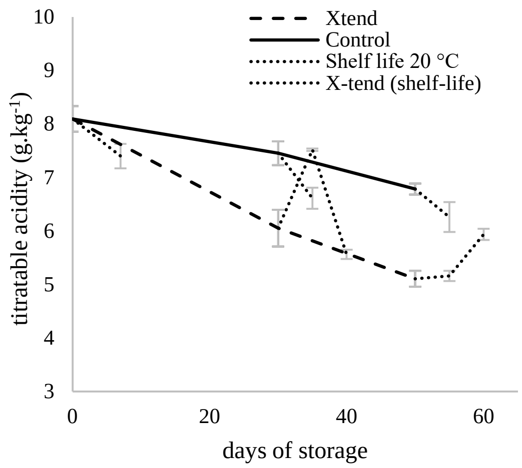


Figure 11 Titratable acidity for the fruit of the 'Kordia' variety when stored at 1 °C, shelf life conditions.

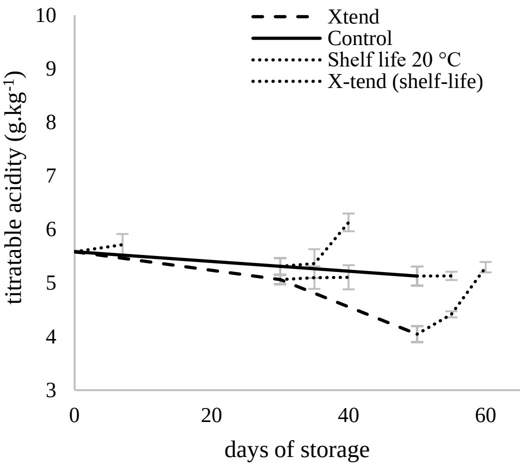


Figure 12 Titratable acidity for the fruit of the 'Vanda' variety when stored at 1 °C, shelf life conditions.

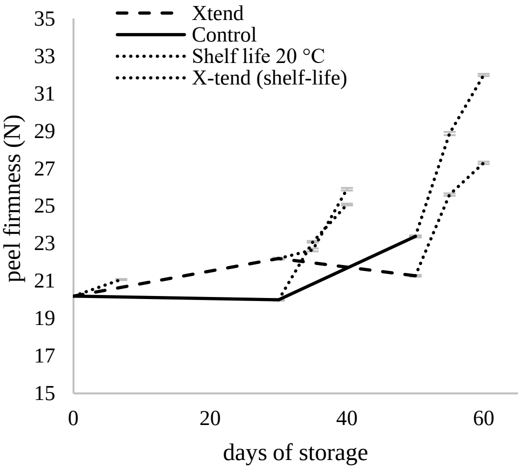


Figure 13 Peel firmness for the fruit of the 'Sweetheart' variety when stored at 1 °C, shelf life conditions.

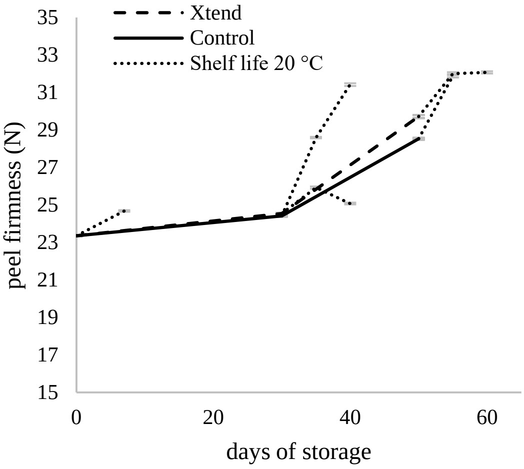


Figure 14 Peel firmness for the fruit of the 'Regina' variety when stored at 1 °C, shelf life conditions.

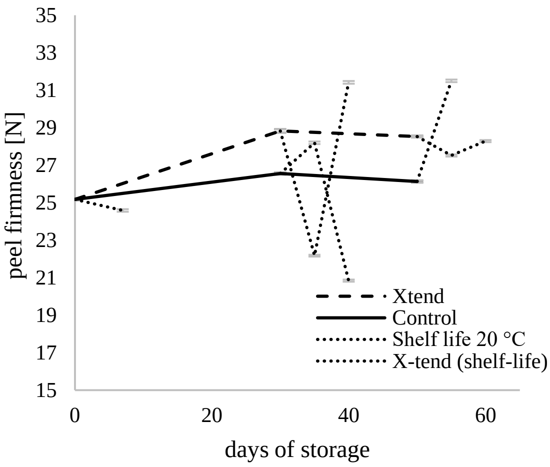


Figure 15 Peel firmness for the fruit of the 'Kordia' variety when stored at 1 °C, shelf life conditions.

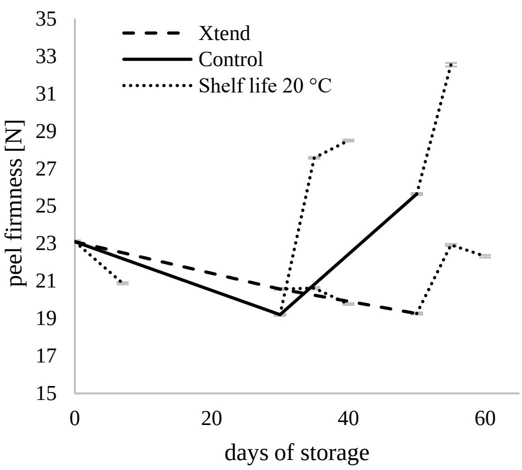


Figure 16 Peel firmness for the fruit of the 'Vanda' variety when stored at 1 °C, shelf life conditions.

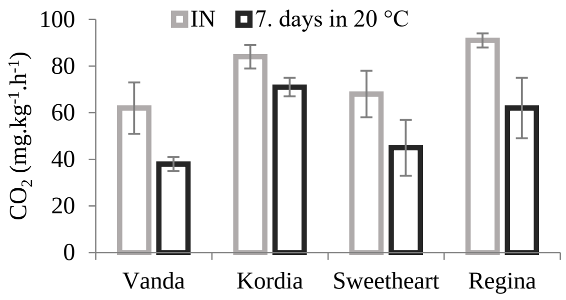


Figure 17 Changes in CO_2 production for cherries stored at 20 °C for 7 days.

respiration intensity in all of the varieties after 7 days; this has a direct relationship to climacteric decline and clearly advanced fruit ripening at this temperature. The smallest decrease in respiration intensity was seen in 'Kordia' (CO_2 production reduced by 17%), 'Regina' (the initial respiration intensity reduced by 32%), 'Vanda' (38% reduction), and 'Sweetheart' (reduction of 34%). Statistical significance is high in all cases.

Since high respiration intensity increases the risk of damage to the fruit during handling, it is advisable to place the fruit to a temperature of 4 – 6 °C after harvest **(Crisosto et al., 1993)**. During storage under refrigerated conditions, respiration intensity was measured on day 30 and day 50. The amount of produced CO_2 was measured immediately after unpacking the air-tight wrap. During 50-day storage a nearly linear rise was observed in Xtend in terms of CO_2 production except for 'Kordia' where a distinct decline occurred for respiration intensity between day 30 and day 50 of storing. Under identical conditions, the monitored varieties packed in Xtend feature intensity of respiration in the following order: 'Vanda' and 'Sweetheart', less 'Regina' and 'Kordia' (Figure 18 – 21). For unpacked fruit, however, this trend was not maintained and the highest CO_2 production was observed for 'Regina', 'Sweetheart', 'Kordia' and 'Vanda' (the lowest level) on day 50 of storage.

After the relocation of the fruit from refrigeration

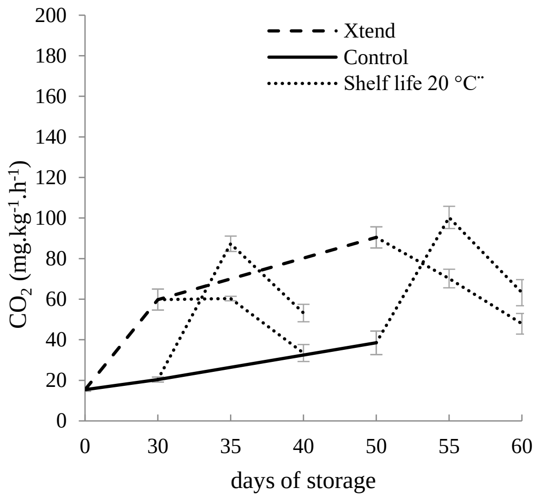


Figure 18 The amount of produced CO_2 for the fruit of the 'Sweetheart' variety when stored at 1 °C, shelf life conditions.

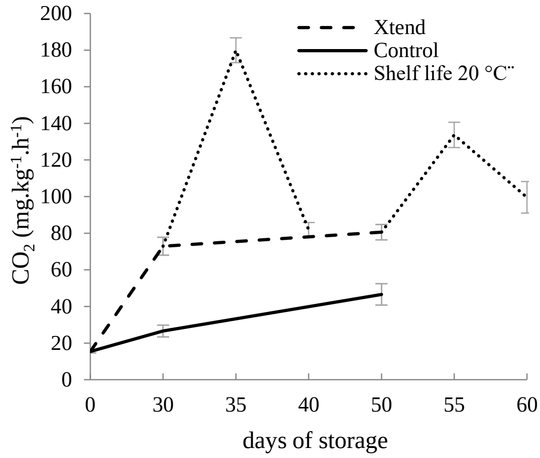


Figure 19 The amount of produced CO_2 for the fruit of the 'Regina' variety when stored at 1 °C, shelf life conditions.

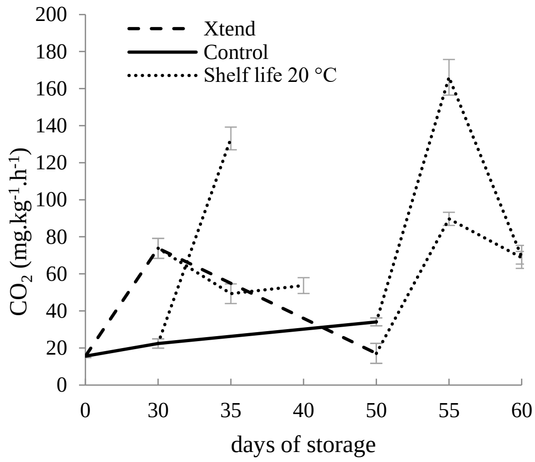


Figure 20 The amount of produced CO_2 for the fruit of the 'Kordia' variety when stored at 1 °C, shelf life conditions.

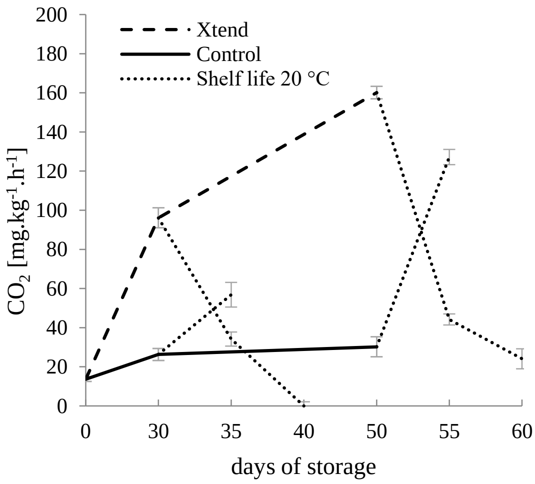


Figure 21 The amount of produced CO_2 for the fruit of the 'Vanda' variety when stored at 1 °C, shelf life conditions.

temperature (1 °C) into the temperature of distribution (20 °C), a high response was seen of fruit to the change in temperature. A different trend was observed in unpacked fruit compared with packed fruit. Fruit which were removed from Xtend reduced the intensity of respiration after placed at 20 °C. Conversely, fruit stored in bulk in the refrigerated room significantly increased the production of CO_2 once placed at higher temperature, which was seen mainly in the initial 5 days. The explanation of opposite waveforms of respiration intensity to identical final temperature arises from the response to a higher temperature in unpacked fruit having a distinct and increasing value due to nothing but the effect of temperature while fruit placed in Xtend were exposed to the higher CO_2 concentration **(Lurie and Weksler, 2008)**.

CONCLUSION

When storing cherries, ambient temperature is undoubtedly an important factor. Higher weight loss in bulk fruit result in reduced quality parameters of stored fruit. Using the Xtend film can partially eliminate wilting of fruit. The evaluation of soluble solids indicates a significant conclusion for storing practice - that is, the fruit does not lose sugar solids even on seven-day storage at the distribution temperature. Testing fruit firmness using a penetration technique is assumed to express the variety's characteristics and flesh reinforcement during storage at 20 °C due to weight loss; such a trend, however, was not observed for all of the varieties during the storage period. At this temperature, the storage of cherries for 7 days is at the limit of consumer quality for two reasons; the first concerns the quality of the stalk, which starts wilting. The second reason involves the fruit which is compact and has the characteristics of consumer quality. Fruit originally packed in an airtight unit with a modified atmosphere adapt through the decreased CO_2 production due to the stress of the higher CO_2 concentration in the fruit and the higher temperature of storage. The lowest values of CO_2 production after 10 days of exposure to a higher temperature are virtually at a comparable level of unpacked fruit. From the viewpoint of the market value of cherry fruit the maximum time that can be applied after removal of fruit from 1 °C to 20 °C is 5 days.

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